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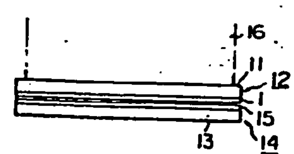
(54) Method of constructing holograms.

(57) A method of constructing a hologram comprises providing a master hologram (12) consisting of a predetermined pattern of interference fringes formed thereon by optical interference of a plurality of constructing coherent light beams incident at different angles; preparing a photosensitive medium (15), in which the hologram is to be formed, on the master hologram; and copying the master hologram onto the photosensitive medium (15) by impinging copying light beams (16) on the master hologram at incident angles different from those of the constructing beams.

Fig. 5



EP 0 087 281 A1

METHOD OF CONSTRUCTING HOLOGRAMS

This invention relates to a method for constructing a hologram which can be used, for example, in a hologram scanner applied, for example, to a point-of-sale (POS) system.

POS systems have come into increasing use in supermarkets, department stores, and other commercial sales outlets in recent years. Use of a POS system enables computer monitoring of a large quantity and variety of goods and, accordingly, automatic calculation and classification of the sales and supply of those goods. In POS systems, information concerning each of the goods is marked directly on the goods in advance by attaching a bar-code label. The bar-codes can be read and detected by the aid of holograms.

A hologram is constructed by optical interference of two coherent light beams. More specifically, a laser source provides a laser beam. The laser beam is separated into two beams, for example, by means of a beam splitter or a half mirror. The first laser beam is, for example, a plane wave (so-called reference wave). The second beam is, for example, a spherical wave (so-called objective wave). These two construction laser beams impinge on a photosensitive layer coated on a transparent glass plate (base plate) at different incident angles. As a result, interference fringes are produced in the photosensitive layer. The interference fringes form so-called diffraction gratings.

In reconstructing a hologram as constructed above, for example, for the purpose of scanning, or copying it, one usually uses reconstruction laser beams having the same incident angle as that of one of the afore-mentioned construction laser beams. Use of such identical laser beams results in maximum diffraction efficiency of th beams since the incident angles of the reconstruction beams ar thus

always Bragg angles with respect to the inclined angles of interference fringe planes of the hologram at any point corresponding to the fringe planes.

Use of such identical reconstruction beams, however, also results in the problem of large aberration of the wavefront obtained by the reconstruction of the hologram.

To decrease aberration, the assignee of this application previously proposed in U.S. Patent Specification No. 4,235,504 to reconstruct a hologram by using reconstruction beams having wavefronts different from those of the construction beams. However, the use of such reconstruction beams different from the construction beams resulted in a decreased diffraction efficiency. That is, it was not possible to decrease the aberration and maintain a high diffraction efficiency at the same time.

In accordance with the present invention, a method of constructing a hologram comprises providing a master hologram plate which has a base plate with a master hologram consisting of a predetermined pattern of interference fringes formed thereon by optical interference of a plurality of constructing coherent light beams incident upon the base plate at different angles; preparing a photosensitive medium in which the hologram is to be formed on the master hologram plate; and copying the master hologram onto the photosensitive medium by impinging a copying light beam on the master hologram at an incident angle different from those of the constructing beams, so that the copying light beam produces transmission beams passing through the associated interference fringes of the master hologram and first-order diffraction beams diffracted by the associated interference fringes of the master hologram, whereby a desired copy hologram having the same pattern of interference fringes as th master hologram is

constructed in the photosensitive medium by optical interference of the transmission beams and the first-order diffraction beams.

This invention provides a method for constructing a hologram from a preconstructed master hologram so as to increase the diffraction efficiency of reconstruction beams and to decrease the aberration.

With this method, the copied hologram has a predetermined pattern of interference fringes identical to that of the master hologram, but the inclined angles of the fringe planes of the copied hologram are different from the inclined angles of the corresponding fringe planes of the master hologram.

Examples of methods in accordance with the present invention will now be described and contrasted with the prior art with reference to the accompanying drawings, in which:-

Figure 1 is a schematic view illustrating the principle of construction of a hologram according to the prior art;

Figure 2 is an enlarged view of a part of Figure 1;

Figure 3 is a longitudinal part sectional view of a hologram showing the relationship between an inclined angle of fringe planes and construction beams of a master hologram used in one example of the present invention;

Figure 4 is a schematic view of a relationship between construction beams and reconstruction beams, according to one example of the invention;

Figure 5 is a schematic view of how to copy a master hologram to construct a copy hologram;

Figure 6 is a schematic view of a copy hologram constructed in accordance with one example of the invention;

Figure 7 is a schematic view similar to Figure 6 but of another example;

Figure 8 is a diagram of known characteristics

of diffraction efficiency of a transmission beam and a first-order diffraction beam;

Figure 9 is a schematic view of still another example;

Figure 10 is a diagram similar to Figure 8, but according to an example of the present invention;

Figure 11 is a schematic view of an embodiment for making intensities of the transmission beams and the first-order diffraction beams identical to each other;

Figure 12 is an enlarged view of a part of Figure 11;

Figure 13 is a diagram of characteristics of transmittance of a filter used in the embodiment shown in Figures 11 and 12;

Figure 14 is a schematic view of a relationship between the copy hologram and the amount of light of copy beams;

Fig. 15 is a schematic view of an embodiment in which a bed supporting a hologram assembly is movable;

Fig. 16 is a plan view of a bed explaining the movements thereof;

Fig. 17 is a schematic view of a variant of Fig. 15, for scanning the beams;

Fig. 18 is a schematic view of an embodiment in which wide copy beams are used;

Fig. 19 is a schematic view of a resultant amount of light of copy beams which are scanned;

Figs. 20 and 21 are schematic views of two successive steps in successive copyings; and

Figs. 22 to 24 are schematic views of three successive steps of production of a multilayered hologram.

As is well known, a hologram is constructed by optical interference of two coherent light beams (construction beams), usually laser beams. In Fig. 1, numeral 11 denotes a transparent glass plate (base plate) with a photosensitive emulsion layer (e.g., silver halide particles dispersed layer) 1 coated thereon. A hologram is formed in the photosensitive layer 1. A laser source (not shown) provides a laser beam. The laser beam is separated into two laser beams 2 and 3 by means of, for example, a beam splitter or half mirror (not shown). The first laser beam 2 is a spherical wave. The second laser beam 3 a plane wave. As shown in Fig. 2, when the plane wave 3 and the spherical wave 2 impinge on the photosensitive layer 1, a predetermined pattern of interference fringes (latent image) 4 are produced along bisector lines of angle α, which is defined by and between the two laser beams and which depends on the impinging points. The interference fringes 4 form so-called diffraction gratings. After that, the glass plate with photosensitive layer is developed and fixed, so that black and white fringes are formed in the photosensitive layer 1. This is a so-called amplitude hologram.

There are generally two kinds of holograms, on of which is the above-mentioned amplitude hologram and the other of which is a phase hologram. A phase hologram is obtained by bleaching the amplitude hologram. That is, silver converts to a transparent silver halide having a large refractive index by bleaching, so that fringes representing refractive index variation are formed in the photosensitive layer 1. This is a phase hologram. Thus a master hologram plate 12 is constructed.

The present invention is applicable to both amplitude and phase holograms, although the following description will be mainly directed to phase holograms.

Referring to Fig. 3, the two beams 2 and 3 are incident on the photosensitive layer 1 at any incident angles θ_1 and θ_2 ($\theta_1 = \theta_2$) with respect to a vertical line X-X normal to the layer 1, respectively. The interference fringe 4 is formed on the bisector line of the two beams, as mentioned above. Namely, the inclined angle α of the fringe plane in which the interference fringe lies is given by the following equation;

$$\alpha = \frac{\theta_1 + \theta_2}{2} \qquad \ldots (1)$$

The angles θ_1 and θ_2 are so-called Bragg angles with respect to the fringe plane having an inclined angle α. The pitch d between the adjacent two fringe planes on the surface of the layer 1 is given by the following relationship;

$$d(\sin\theta_1 + \sin\theta_2) = n\lambda \qquad \ldots (2)$$

wherein n is the order of diffraction of the associated beam and λ a wavelength of the associated beam.

As is well known, when a reconstruction beam identical to the construction beam 2 is used, a part of the reconstruction beam is a transmission beam 2' and another part of the reconstruction beam is a first-order diffraction beam 3' which is identical to a transmission beam of the construction beam 3. Similarly, when a reconstruction beam identical to

0087281

the construction beam 3 is used, a part thereof is the transmission beam 3' and another part of the reconstruction beam is a first-order diffraction beam 2' identical to the transmission beam of the construction beam 2. In this way, the reconstruction beam is most effectively used, but results in a large aberration, as mentioned before.

As disclosed in the aforementioned USP 4,235,504, when a hologram is reconstructed, for example, for scanning the laser beam, it is desirable to use a reconstruction laser beam (e.g., plane wave) 5 having an incident angle θ' different from those (θ_1 and θ_2) of the construction beams 2 and 3 in order to decrease the aberration of the wavefront obtained by the reconstruction of the hologram. The present invention also uses such a reconstruction beam 5 for the purpose of decrease of aberration.

In Fig. 3, when the reconstruction beam 5 impinges on the fringe plane 4 at an incident angle θ' with respect to the surface plane of the layer 1, a part of the beam 5 is transmission beam 5' and a part of the beam 5 is a first--order diffraction beam 6.
In the embodiment shown in Fig. 4, the reconstruction laser beams 5A, 5B, 5C, etc. (plane wave) from a same laser beam source (not shown) are incident on the hologram (the photosensitive layer 1 with a predetermined pattern of interference fringes 4) at a right angle i.e., perpendicular to the plane of the photosensitive layer. That is, the incident angle θ' is 0°, and neither identical to θ_1 nor to θ_2. The reconstruction beams 5A, 5B and 5C are split into transmission beams 5A', 5B', and 5C' and first-order diffraction beams 6A, 6B, and 6C by the hologram, respectively. To scan the laser beams by the use of the arrangement shown in Fig. 4, the reconstruction laser beams 5A, 5B, and 5C are moved relative to the hologram in the direction <u>A</u> or the hologram is moved relative to the reconstruction beams in the direction <u>B</u>. The reconstruction laser beams are not limited to a plane wave, but may be a spherical wave. The spherical wave can be deemed to be a

plane wav since the diameter of a laser beam spot on th hologram is very small (about 2 mm), provided that th distance between the hologram and the laser beam source is, for example, more than 160 mm, resulting in a small spread angle of the reconstruction beam.

According to the present invention, based on the principle described above, a hologram is constructed by copying the master hologram plate 12 with the use of a copy beam which is identical to the aforementioned reconstruction beam 5. The hologram will be referred to as a copy hologram for distinguishing it from the master hologram.

A copy hologram plate 14 which has a transparent glass plate 13 with a photosensitive layer 15 coated thereon is superimposed on the master hologram plate 12 in such a way that the hologram, i.e., the photosensitive emulsion layer 1 with a predetermined pattern of interference fringes 4, of the master hologram plate 12 faces and comes into close surface contact with the photosensitive layer 15 of the copy hologram plate 14, as shown in Fig. 5. It should be noted that although the two layers 1 and 15 are slightly spaced from one another for clarification, they are in close contact with each other over the surface areas thereof. Copy beams 16 which are, for example, identical to the reconstruction beams 5A, 5B, and 5C impinge on the master hologram plate 12 at an incident angle, preferably equal to 0°, from the side of the glass plate 11. Consequently, the copy beams 16 are split into first-order diffraction beams 17 and transmission beams 18. Second-order, third--order, ---, and n-order diffraction beams are not considered herein. A predetermined pattern of interference fringes 19 are formed in the photosensitive layer 15 on bisector lines between the transmission beams 18 and the first-order diffraction beams 17, as shown in Fig. 6. The transmission beams 18 and th first-ord r diffraction beams 17 serve as construction b ams corresponding to the beams 2 and 3 (Fig. 1) for constructing the copy hologram. The inclined angl s α' of the int rference fringe planes of th copy

hologram are different from the inclined angles α of the corresponding interference fringe planes of the master hologram. The pattern of the interference fringes of the master hologram does not change and is the same as the pattern of the interference fringes of the copy hologram. When the copy hologram thus obtained is reconstructed, for example, for scanning the laser beam, a reconstruction beam identical to the beam 16 is used so that the refraction efficiency of the reconstruction beam is maximum because the two beams 17 and 18 split from the beam 16 satisfy the Bragg condition with respect to the copy hologram.

Namely, according to the present invention, the problem of aberration is solved when the master hologram is constructed, and the problem of diffraction efficiency is solved by copying the master hologram.

In an arrangement shown in Fig. 7, the copy beams 20 are identical to the first-order diffraction beams 6A, 6B, and 6C in Fig. 4 in place of to the transmission beams 5A', 5B', and 5C'. Similarly to Fig. 6, the interference fringes 23 are produced on the bisector lines between the transmission beams 21 and the first-order diffraction beams 22 in the photosensitive layer 15 of the copy hologram. A copy hologram the same as that shown in Fig. 6 is obtained in a similar fashion to Fig. 6.

As can be understood from the above discussion, according to the present invention, the inclined angles of the fringe planes can be controlled independently of the two-dimensional distribution or pattern of the interference fringes.

It is known that diffraction efficiencies of a transmission beam (plane wave) and a first-order diffraction beam (spherical wave) with respect to an incident angle θ of a reconstruction beam are as shown in Fig. 8. In Fig. 8, the curves C and D correspond to the transmission beams and the first-order diffraction beams, respectively. As can b seen from Fig. 8, the diffraction efficiency of the first-order diffraction beams represented by the curve D is maximum at

the angle θ_i , which is an incident angle of reconstruction beams identical to one f the two kinds of construction beams which have been used for constructing the hologram, but the diffraction efficiency of the transmission beams is minimum at the angle θ_i. Namely, when the hologram is reconstructed by use of reconstruction beams (incident angle θ_i) identical to one of the two construction beams, the itensity of the first-order diffraction beams (e.g., 6A) is about 3 to 10 times the intensity of the transmission beams (e.g., 5A'). Such a large difference in intensity between the two split beams, i.e., the transmission beams and the first-order diffraction beams, may be particularly disadvantageous when the hologram is adapted to split a laser beam, i.e., when the hologram is used as a beam splitter. Therefore, if the intensities of the two beams split by the hologram must be identical to each other, the incident angle θ of the copy beams is selected to be $\theta_i - \theta_1$ (or $\theta_i + \theta_1$), at which the curves C and D intersect, i.e., at which the intensities of the transmission beams and the first-order diffraction beams are identical to each other.

Figure 9 shows an arrangement in which the copy beam 24 impinges on the master hologram plate 12 at an incident angle equal to $\theta_i + \theta_1$ to construct the copy hologram plate 14. In this arrangement, the intensity of the transmission beams 24' is identical to that of the first--order diffraction beams 25.

Figure 10 shows diffraction efficiencies of the transmission beams (C') and the first-order diffraction beams (D') when an incident angle θ of the reconstruction beams (copy beams) are $\theta_i + \theta_1$ ($\theta = \theta_i + \theta_1$). Therefore, when the copy hologram obtained by the invention is reconstructed, the incident angle of the reconstruction beams can be selected to be θ_i , in order to make the intensities of the transmission beams and the first-order diffraction beams split by the copy hologram equal to each other. Therefore, the copy hologram according to the invention can be advantageously used also as a b am splitter.

It will be appreciated that any desired ratio of the diffraction efficiency between the transmission beams and the first-order diffraction beams can be obtained by properly selecting the incident angle θ of the copy beams 24 (Fig. 9).

Figure 11 shows a different embodiment for making the intensities of the transmission beams and the first-order beams identical to each other. In Fig. 11, a filtering thin layer 50 is formed on the master hologram (i.e., the photosensitive layer 1 having the master hologram recorded therein). The layer 50 is made of, for example, SiO_2 or TiO_2 having a transmittance as shown in Fig. 13. The layer 50 can be coated on the master hologram, for example, by a known evaporation coating method. Supposing that a copy beam 20 impinges on the master hologram plate 12 at an incident angle θ_0, the beam 20 is split into a transmission beam 20A and diffraction beams 20B, 20C, 20D, etc., by an interference fringe 4 of the master hologram. The diffraction beams 20B, 20C, and 20D are a minus first-order diffraction beam, a plus first-order diffraction beam, and a plus second diffraction beam, respectively. The angles of the diffraction beams 20B, 20C, and 20D, with respect to the vertical direction are represented by θ_B, θ_C, and θ_D, respectively. The angle of the transmission beam 20A is represented by θ_A. The angles θ_A, θ_B, θ_C, and θ_D are also incident angles with respect to the thin layer 50. By properly selecting the distance (pitch) d (Fig. 3) between the interference fringe planes of the master hologram and the incident angle θ_0 of the copy beam 20, the angle θ_C can be set to be smaller than all of the angles θ_A, θ_B, and θ_D. That is,

$$|\theta_C| < |\theta_A|, |\theta_B|, |\theta_D|$$

Under the above-mentioned condition, the transmittance of the filtering layer 50 has characteristics as shown in Fig. 13. In Fig. 13, the transmittance τ_A, τ_B, τ_C, and τ_D correspond to the incident angles θ_A, θ_B, θ_C, and θ_D, respectively. Since the intensity decreases as the number (absolute value) of diffraction increases, the

intensity I_A of the transmission beam 20A is larger than th intensity I_C of the first-order diffraction beam 20C. That is, $I_A > I_C$. Therefore, in order to make the intensities of the transmission beam 20A and the first--order diffraction beam 20C past the filtering layer 50 identical to each other, the transmittance characteristics of the filtering layer 50 must satisfy the following relationship;

$$\tau_C \times I_C = \tau_A \times I_A$$

Thus, transmission beams and first-order diffraction beams having the same intensity can be obtained.

As can be seen from Fig. 13, since τ_B is equal to zero and τ_D is almost equal to zero, the minus first-order diffraction beams 20B and the second-order diffraction beams 20D can be substantially intercepted by the filtering layer 50, so that a copy hologram having a fringe pattern exactly corresponding to that of the master hologram except the inclined angles α of the interference fringe planes can be constructed by the interference of the transmission beams and the first-order diffraction beams. Experimental results showed that when the copy beam 20 having a wavelength of 632.8 nm (nanometer) impinged on the master hologram plate having interference fringes at a pitch of 2 µm, at an incident angle of 15° (θ_0 = 15°), the angles θ_A, θ_B, θ_C, and θ_D were 3°, 15°, 22°, and 35°, respectively. A filtering layer 50 having transmittance-incident angle characteristics as shown in Fig. 13 can be easily prepared. The thickness of the layer 50 depends on a refractive index of the layer and is usually on the order of a few µm.

When the copy beams or construction beams 16 are incident at one time over the entire width W of the master hologram plate 12, as shown in Fig. 14, the distribution of the amount of light is as shown by the curve E. This is because the laser beams emitted from a laser beam source are spread by a lens (not shown). That is, the exposur is maximum at the center of the hologram and becom s smaller toward the peripheri s thereof. This irregular distribution

of the amount of light or exposure may result in an imperfect copy of the master hologram. To solve this problem, the master hologram plate 12 and the copy hologram plate 14 on which a copy hologram is to be formed are preferably located on a movable bed or table 30. As mentioned above, the master hologram plate 12 is superimposed on the copy hologram plate so that the master hologram (i.e., photosensitive layer 1) comes into close surface contact with the photosensitive layer 15 of the copy hologram plate when copying is effected. The assembly thus formed is put on the movable bed 30, capable of moving in X-Y directions (Figs. 15, 16) in a horizontal plane. The two-dimensional movement of the bed 30 can be effected, for example, by a numerical controller (NC) 31 or hydraulic device (not shown), per se known. In Fig. 15, numerals 33, 35, and 37 designate a stationary laser beam source, a collimator, and spot-like laser beams, respectively. The bed 30 reciprocates in the direction X and moves by one pitch at one time in the direction Y, as shown in Fig. 16, so that the laser beams 37 can be scanned over the entire surface of the master hologram plate 12 from above.

Alternatively, it is also possible to directly scan the laser beams 37 without moving the bed in the direction X, as shown in Fig. 17. In Fig. 17, the bed 30' moves in step motion only in the direction Y. The laser beams 37 emitted from the laser beam source 33 are swung through an angle β by means of an optical deflector or an optical scanner 40, per se known, to cover the width W (Fig. 14) of the master hologram plate. The optical scanner 40 may be also, for example, a galvanometer which oscillates to scan the laser beams. The optical scanner 40 is available on the market, for example, from General Scaning Inc. of the U.S.

In an arrangement shown in Fig. 18, the laser beams 37 which are spread by a lens 41 are used. In this arrangement, the distribution of the amount of light is not uniform, as mentioned before and as shown in Fig. 14. In order to make the distribution of the amount of light uniform over the

0087281

entire surface of the master hol gram plate 12, th movabl bed 30 is moved in the directions X-Y, as mentioned above with reference to Figs. 15 and 16. By the two-dimensional movement of the movable bed 30, the curve representing the amount of light changes as designated by E_1, E_2, E_3, etc. in Fig. 19, so that the resultant curve of the amount of light becomes as E_0. Thus, even when the spread copy beams 37 are used, a uniform distribution of the amount of light as designated by the curve E_0 can be obtained by moving the bed 30. It can be easily understood that the uniform distribution in question can be achieved also by moving an optical laser system having the laser beam source (not shown) and the lens 41 in place of the movement of the bed 30. Furthermore, the reciprocal movements in the directions X and Y can be replaced by circular movement of the optical laser system or the bed along a circle having a center located at a center of the master hologram plate.

As reiterated hereinbefore, according to the invention, the incident angles θ of the copy beams are different from those of the two construction beams 2 and 3 used to construct the master hologram. However, when there is a large difference in incident angle between the copy beams and the construction beams, only a small amount of light of first--order diffraction beams can be produced, which is not enough to produce a clear contrast between the interference fringes and the remaining sections, resulting in a low quality hologram. This problem can be solved by an embodiment shown by Figs. 20 and 21.

Supposing that the copy hologram is finally constructed by the copy beams 16 perpendicular to the master hologram plate, as shown in Fig. 5, a first copy hologram plate 14' is first constructed by copying the master hologram with the use of first copy beams 16A which are inclined at an angle γ_1 with respect to the vertical axis X-X (i.e., the final copy beams 16) and which lie, for example, betwe n the construction beams 3 and the vertical axis X-X. Consequently, a first copy hologram plate 14' which has a photosensitive

layer 15' having a predetermined pattern of copy hologram therein is constructed, as shown in Fig. 20. The inclined angle α (Fig. 3) of the copy hologram of the first copy hologram plate 14' is different from and is smaller than a finally desired inclined angle of the final copy hologram. Then, the first copy hologram plate 14' is used as a master hologram plate corresponding to the master hologram plate 1 shown in Fig. 5 to construct a second copy hologram plate 14" with a photosensitive layer 15" having a predetermined pattern of a second hologram by the use of copy beams 16B which are inclined at an angle γ_2 with respect to the vertical axis X-X. The angle γ_2 is smaller than the angle γ_1. That is, the second hologram is constructed by copying the first hologram, in a similar method to Fig. 5. Such copying operations are repeated by using successive copy beams which change in inclined angle γ with respect to the vertical axis little by little. Finally, the vertical copy beams 16 as shown in Fig. 5 are used to construct a finally desired copy hologram. According to the method shown in Figs. 20 and 21, since successive copies are repeated by using successive copy beams which have inclined angles gradually approaching that of the desired final copy beams, a desired hologram having a clear contrast can be obtained. The successive copy beams have, preferably, the same wavefronts, and, for example, are all plane wave, but are not limited thereto.

On copying the copy hologram from the master hologram, the copy hologram plate must be in close surface contact with the master hologram plate. Failure of close surface contact between the master hologram and the photosensitive layer on which the copy hologram is to be constructed results in production of an unclear pattern of interference fringes on the copy hologram plate due to a decrease of diffraction efficiency and in production of undesirable copy fringes in the copy hologram. In order to eliminate these disadvantages, according to an embodiment illustrated in Figs. 22 to 24, a multilayered hologram is provided. That is, the photosensitive layer 15 in which a copy hologram is

to be constructed is directly formed on the master hologram without providing the glass plate 13 for the copy hol gram. In Figs. 22 to 24, the master hologram 4 is constructed in the photosensitive layer 1 of the glass plate 11 by the method of the invention mentioned above. When the master hologram is constructed, the construction beams 2 (Bragg angle = θ_1) and 3 (Bragg angle = θ_2) (Fig. 3) to be used have small diffraction efficiencies. The master hologram may be either the amplitude hologram or the phase hologram. The diffraction efficiency is, preferably, about 5% to 10% in case of the phase hologram and about 1% to 2% in case of the amplitude hologram. It is known that a hologram pattern presents a clear contrast and the diffraction beams have high intensity when the photosensitive layer for the hologram is subject to sufficient exposure and vice versa. Therefore, a low diffraction efficiency hologram can be easily obtained by adjusting, i.e., decreasing the exposure. Then, the photosensitive layer 15 is coated directly on the photosensitive emulsion layer 1 of the master hologram plate 12. After that, the copy beams 20 impinge on the glass plate 11 of the master hologram plate 12 at an angle θ_0 with respect to the vertical direction. The angles θ of the copy beams 20 are different from those (θ_1 and θ_2) of the construction beams 2 and 3, according to the invention. By the exposure of the layer 15 by means of the first-order diffraction beams 22 and the transmission beams 21, a latent image of a fringe pattern, i.e., a copy hologram is formed in the layer 15. The interference fringes are on the bisector lines 49 between the associated transmission beams and the first-order diffraction beams, as mentioned before. The latent image appears by developing and fixing the glass plate 11 with the multilayered photosensitive emulsions 1 and 15, so that the copy phase hologram 23 is constructed (Fig. 23). Since the inclined angle of the fringe planes of the copy hologram 23 is different from that of the fringe planes of the master hologram 4, as mentioned above, the presenc of the master hologram can be disregarded when the

diffraction efficiency of the copy hologram is considerably large in comparison with that of the master hologram. Thus, the copy hologram having the Bragg angle θ is provided directly on and integrally with the master hologram plate (Fig. 24). Therefore, there is no fear of failure of close surface contact between the master hologram and the copy hologram. In the copy hologram shown in Fig. 24, the reconstruction beams 51 impinging on the copy hologram at an angle θ with respect to the vertical direction are used, so that the Bragg condition is satisfied, resulting in production of diffraction beams 53 having the maximum intensity. The numeral 55 in Fig. 24 designates transmission beams. If the base hologram is of the amplitude type, the copy hologram 15 is converted to the phase hologram by bleaching it, if necessary. It will be appreciated that since the material of the photosensitive emulsion layer 15 can be properly selected so as to make the intensities of the transmission beams 21 and the first-order diffraction beams 22 identical to each other as mentioned before, the interference fringes of the copy hologram can be clearly made. By using the first-order diffraction beams 53 diffracted by the copy hologram, the copy hologram can be advantageously used as a hologram scanner.

Example 1

This example is directed to an amplituide type master hologram. Two beams of an Ar laser were applied incident on Kodak 120-01 (tradename) at angles of ±15° with respect to the vertical direction. The angle defined by and between the two beams was 30°. After the development and fixing treatments, a low diffraction efficiency amplitude hologram (master hologram) 4 having an optical density (OD) of about 0.4 was constructed. The Bragg angles of the hologram are ±15° (= θ). On the hologram thus obtained was then coated a thin layer (photosensitive layer 15) of 4 to 5 μm consisting of dichromated gelatin. After that, the copy beams 20 of the Ar laser were applied incident on the thin layer 15 from the side of the master hologram at an incident

angle 30° with resp ct to th v rtical direction to expose the dichromated gelatin. After exposur , the dichromated gelatin was developed and fixed. Consequently, the dichromated gelatin was converted to a phase type copy hologram 23 having a Bragg angle of 30° and a diffraction efficiency above 70%. The entire assembly was bathed in Bromine gas, so that the amplitude type master hologram 4 was bleached and converted to a phase type hologram. However, since the phase master hologram has a small optical density of 0.4, the diffraction efficiency thereof was small enough to be ignorable. Thus, as a whole, a phase hologram having a Bragg angle of 30° (= θ) and a diffraction efficiency above 70% was obtained.

Example 2

This example is directed to a phase type master hologram. As the master hologram base plate was used a glass plate 11 with a photosensitive layer 1 having a thickness of 1 to 2 μm and consisting of polyvinyl carbazole (PVCz) coated thereon. Two beams of an Ar laser were applied incident on the base plate in a way similar to Example 1. After the development and fixing treatment, a phase type master hologram 4 having a Bragg angle of ±15° and a diffraction efficiency of 5% to 10%, was obtained. A thin layer of 4 to 5 μm consisting of PVCz was coated on the master hologram. The copy beams 20 of the Ar laser were then applied incident on the thin layer at an incident angle of 30° to expose the PVCz layer. The PVCz layer was converted to a phase type copy hologram 23 having a Bragg angle of 30° and a diffraction efficiency of about 70%. The master hologram located under the copy hologram had a small diffraction efficiency ignorable in comparison with that of the copy hologram. Therefore, a two-layered phase type hologram was constructed similarly to Example 1.

CLAIMS

1. A method of constructing a hologram, the method comprising providing a master hologram plate (12) which has a base plate (11) with a master hologram consisting of a predetermined pattern of interference fringes formed thereon by optical interference of a plurality of constructing coherent light beams incident upon the base plate at different angles; preparing a photosensitive medium (15), in which the hologram is to be formed, on the master hologram plate; and copying the master hologram onto the photosensitive medium (15) by impinging a copying light beam (16) on the master hologram at an incident angle different from those of the constructing beams, so that the copying light beam produces transmission beams (18) passing through the associated interference fringes of the master hologram and first-order diffraction beams (17) diffracted by the associated interference fringes of the master hologram, whereby a desired copy hologram having the same pattern of interference fringes as the master hologram is constructed in the photosensitive medium (15) by optical interference of the transmission beams and the first-order diffraction beams.

2. A method according to claim 1, wherein the photosensitive medium (15) comprises a photosensitive layer directly coated on the master hologram.

3. A method according to claim 1, wherein the photosensitive medium comprises a copy hologram base plate (13) which has a photosensitive layer (15) coated thereon and which is superimposed on the master hologram plate so that the photosensitive layer comes in close surface contact with the master hologram.

4. A method according to any of claims 1 to 3, wherein the copying beam (16) is incident upon the master hologram at an angle perpendicular thereto.

5. A method according to any of the preceding claims, wherein the copying beam (16, 20) has incident angles identical to those of the transmission beams with respect to the photosensitive medium or identical to those of the first-order diffraction beams with respect to the photosensitive medium.

6. A method according to any of claims 1 to 4, wherein the copying beam has incident angles equal to incident angles of the transmission beams and the first-order diffraction beams at which the two kinds of beams have a same diffraction efficiency.

7. A method according to any of the preceding claims, further comprising coating a filtering layer (50) on the master hologram prior to the provision of the photosensitive medium (15) onto the master hologram plate, the filtering layer having a transmittance which decreases as the incident angle of the beams incident thereupon with respect to a line perpendicular to the filtering layer increases selectively to interpept the beams having an incident angle above a predetermined value.

8. A method aocording to any of the preceding claims, wherein the copying beam (16) comprises spot-like beams.

9. A method according to any of claims 1 to 7, wherein the copying beam (16) has a predetermined width of beams impinging over the master hologram.

10. A method according to any of the preceding claims, wherein the copying beam (16) and the master hologram plate are moved relatively to one another.

11. A method according to claim 10, wherein the master hologram plate (12) is moved in two-dimensional directions, together with the photosensitive layer (15) for the copy hologram, relative to the copying beam (16).

12. A method according to any of the preceding claims, further comprising, subsequent to preparing the first copy hologram, preparing a second photosensitive medium (15"), in which a second hologram i.e. the desired hologram is to be formed, on the first copy hologram (15'); copying the first copy hologram onto the second photosensitive medium (15") by impinging a second copying light beam (16B) on the first copy hologram at an incident angle different from those of the constructing beams and from that of the first copying light beam (16A), so that the desired hologram having the same pattern of interference fringes as the master hologram is constructed in the second photosensitive medium (15") in a similar way to the construction of the first copy hologram.

13. A method according to claim 12, comprising repeating the copying steps in which a copy hologram constructed in the preceding copying step is used as a master hologram which is to be copied to construct a succeeding copy hologram.

14. A copy hologram prepared in accordance with any of the preceding claims.

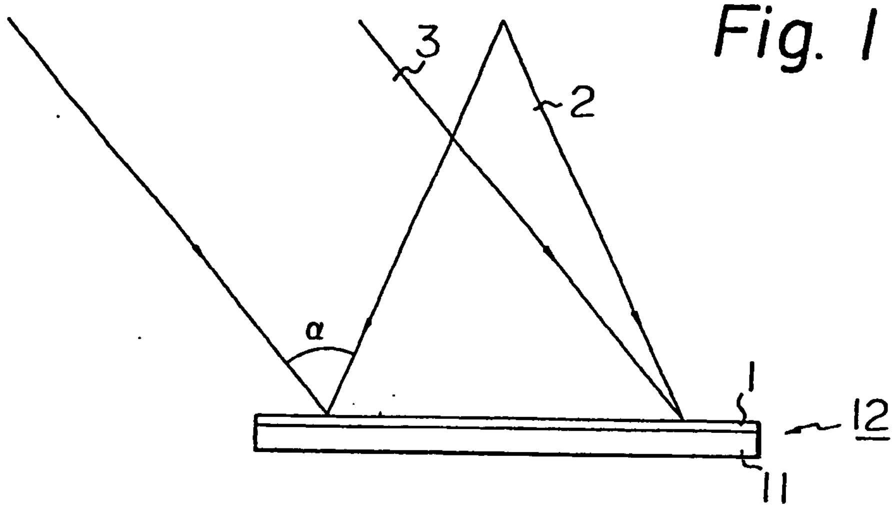
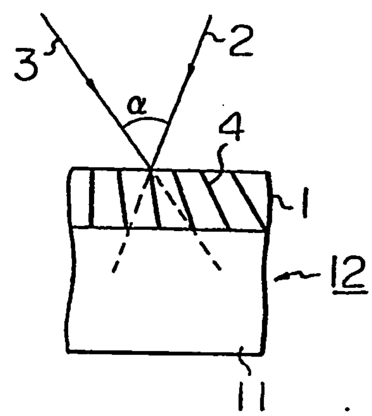


Fig. 1

Fig. 2



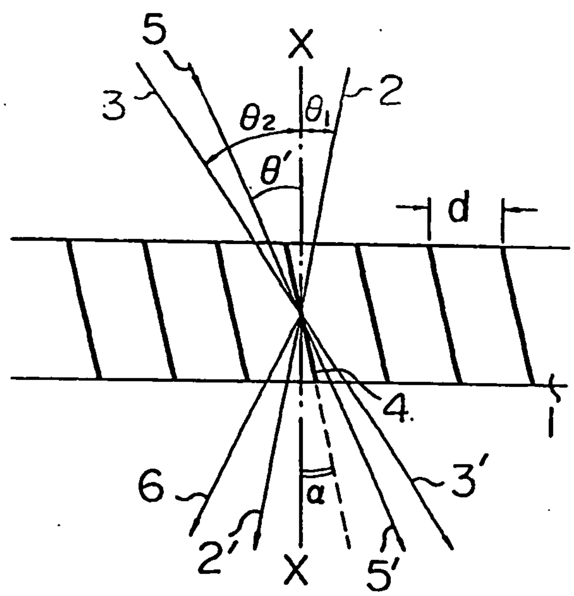


Fig. 3

Fig. 4

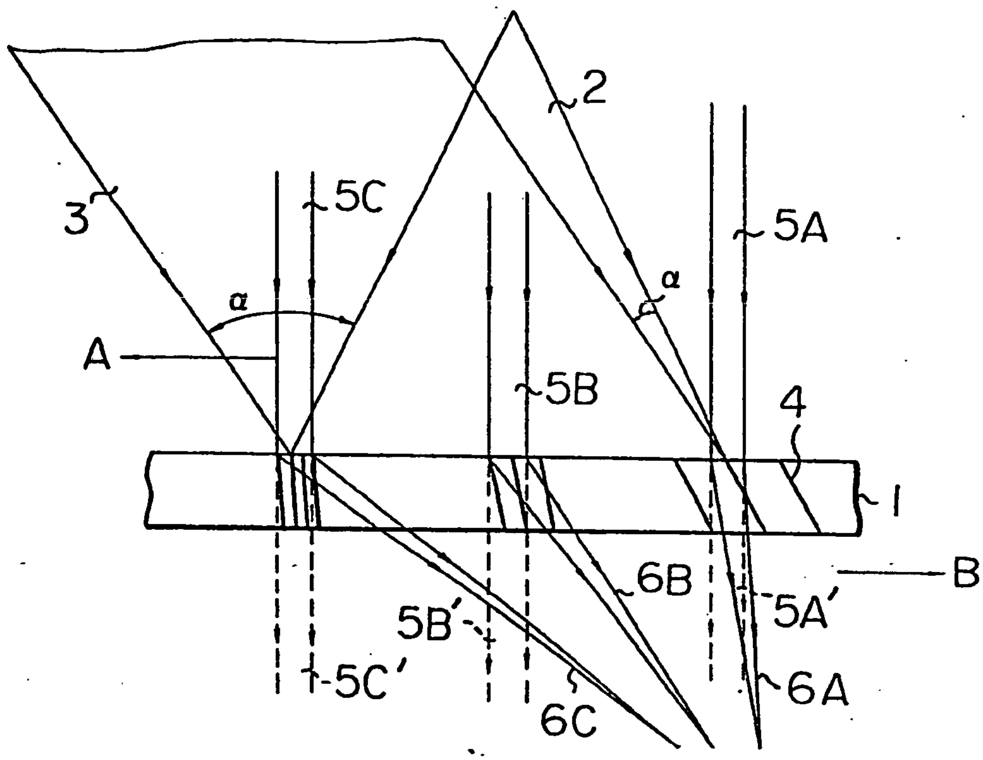


Fig. 5

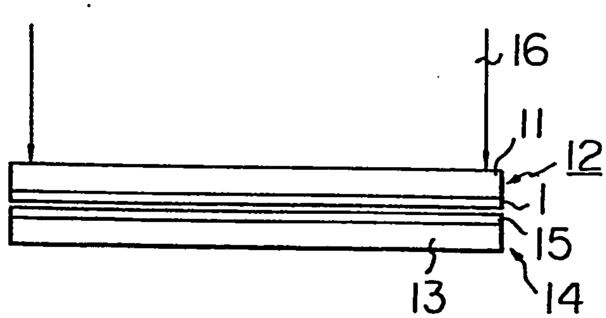


Fig. 6

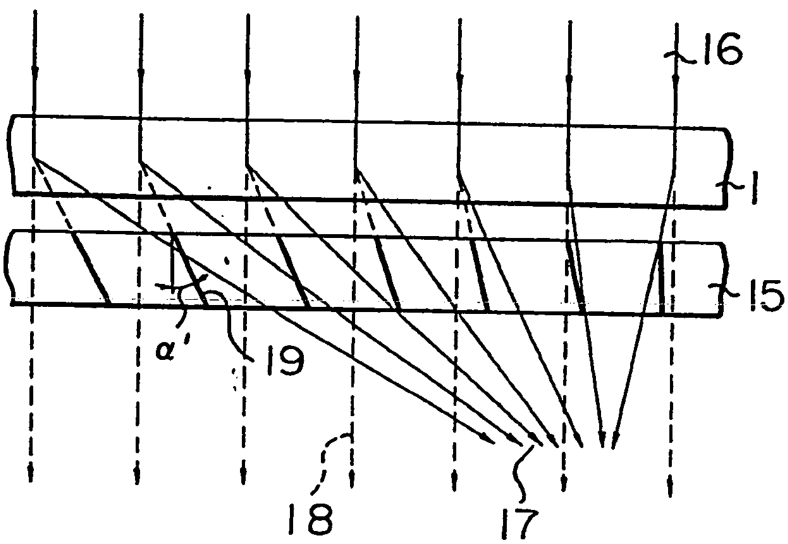


Fig. 7

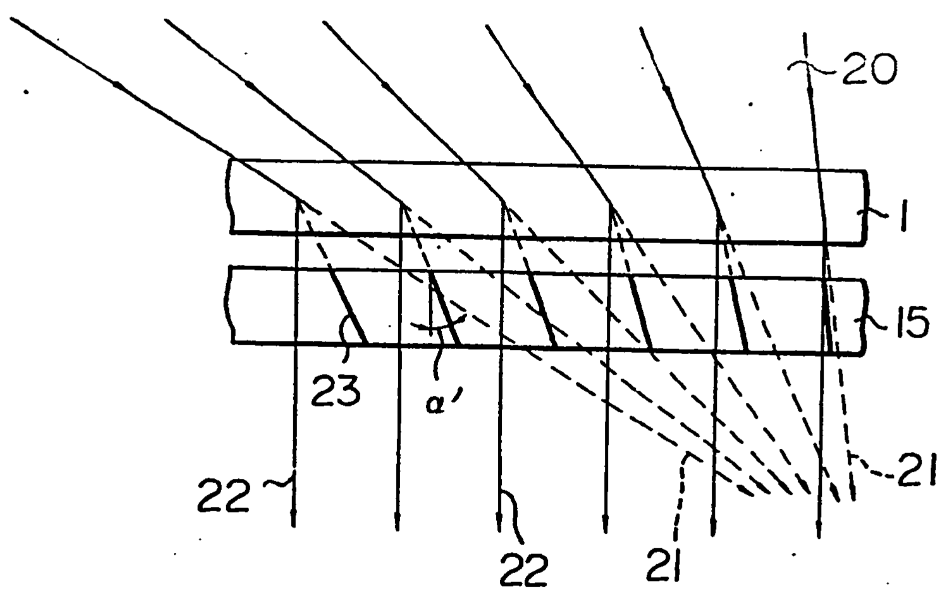


Fig. 8

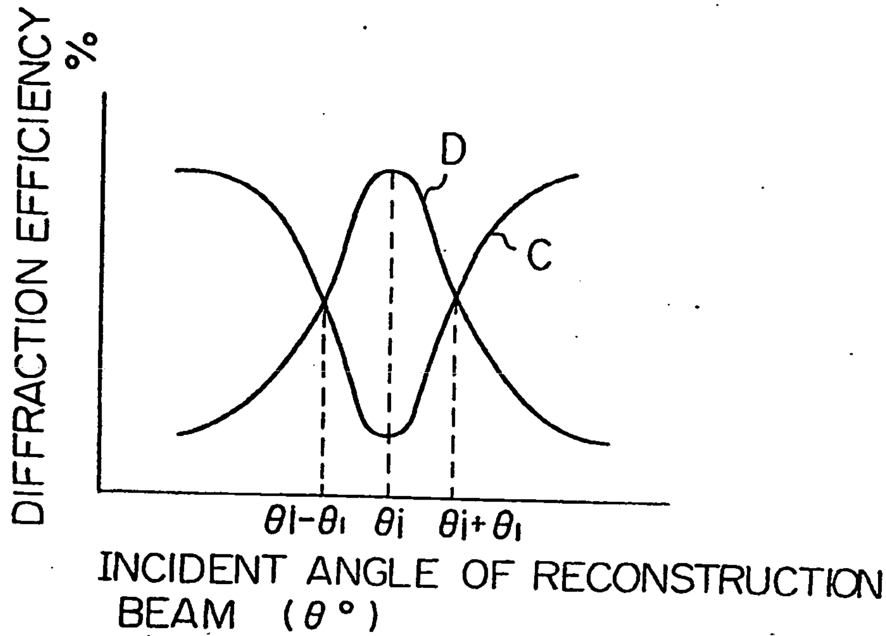

DIFFRACTION EFFICIENCY %
D
C
θl−θ1
θi
θi+θ1
INCIDENT ANGLE OF RECONSTRUCTION BEAM (θ°)

Fig. 9

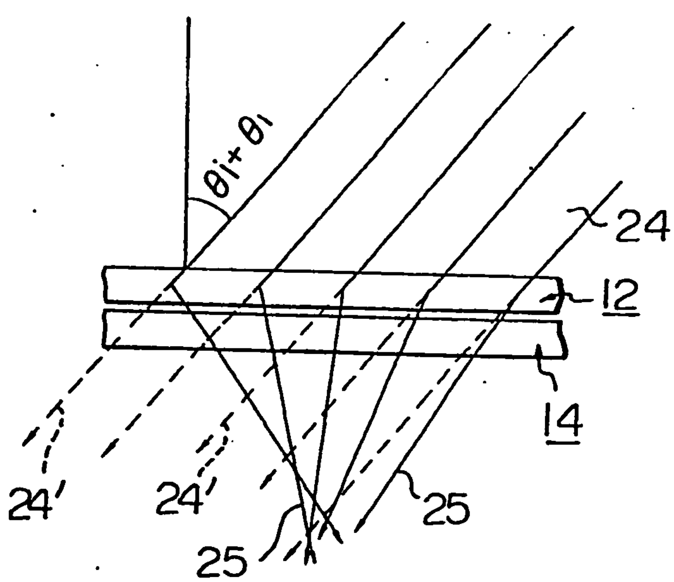

θi+θ1
24
12
14
24'
24'
25
25

Fig. 10

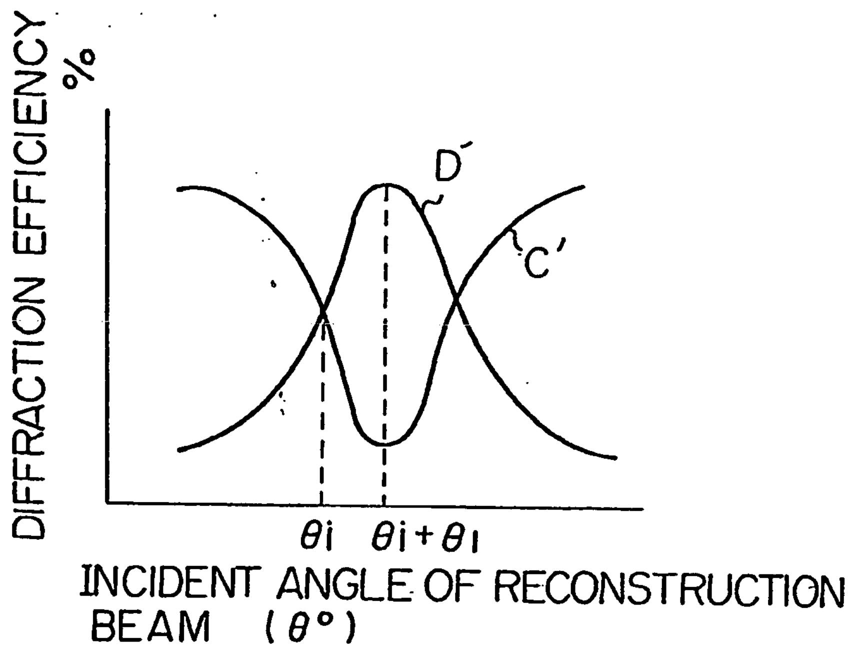

DIFFRACTION EFFICIENCY %
D′
C′
θi
θi+θ1
INCIDENT ANGLE OF RECONSTRUCTION BEAM (θ°)

Fig. 11

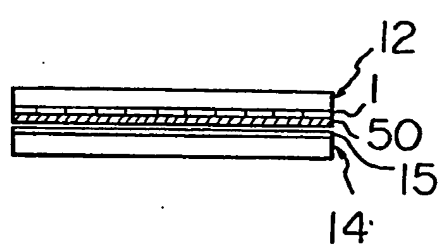

12
1
50
15
14

Fig. 12

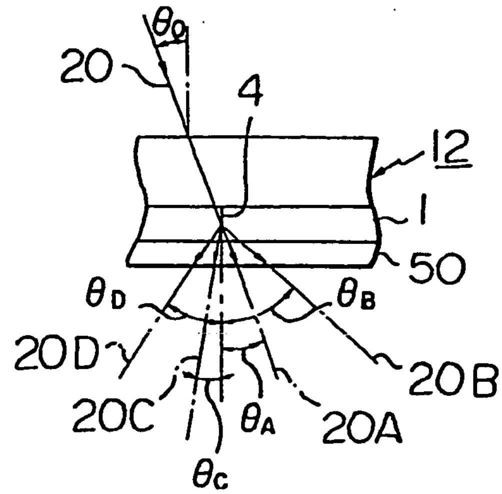

θ0
20
4
12
1
50
θD
θB
20D
20B
20C
θA
20A
θC

Fig. 13

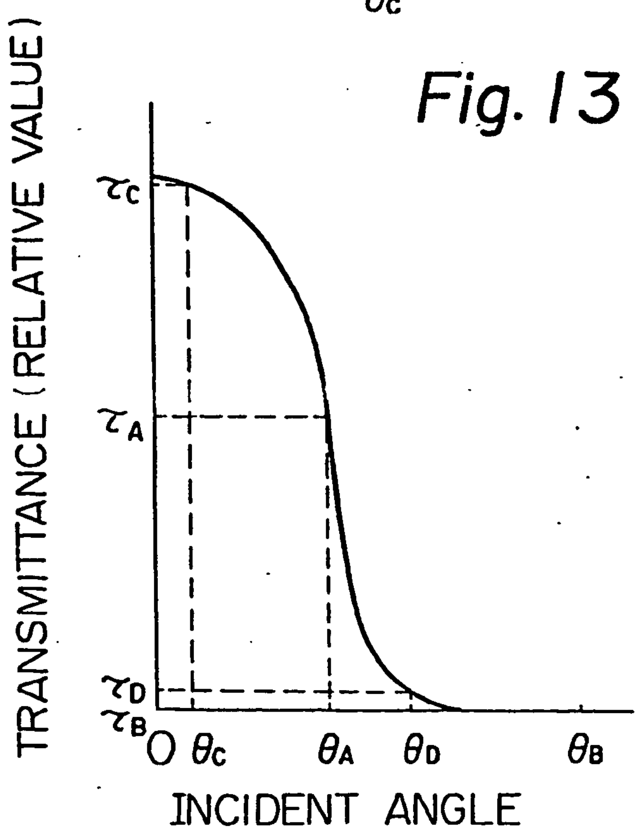
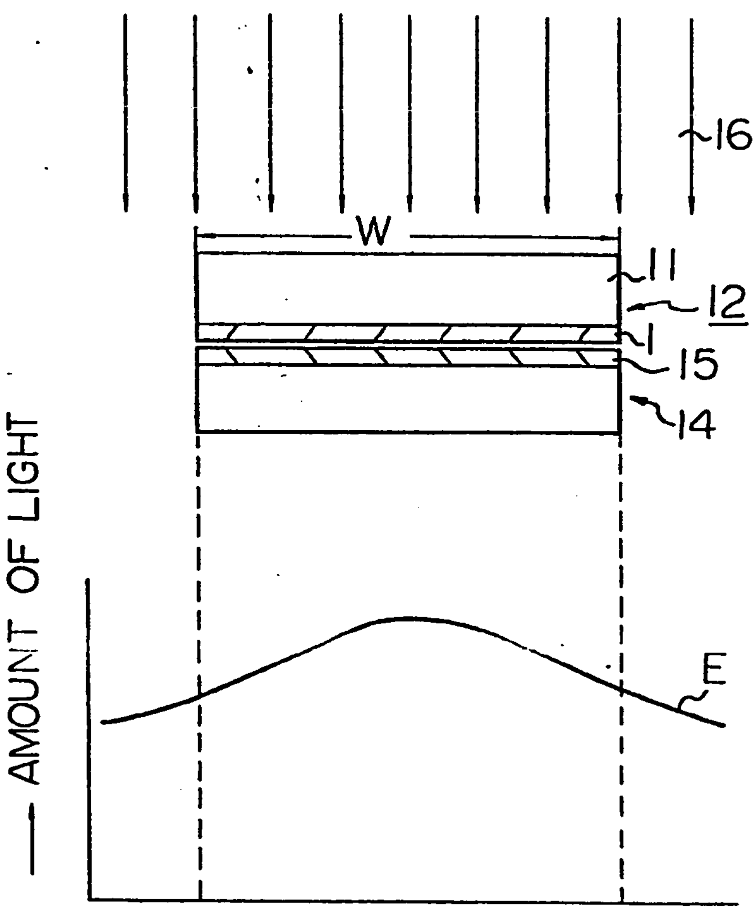

TRANSMITTANCE (RELATIVE VALUE)
τC
τA
τD
τB
O
θC
θA
θD
θB
INCIDENT ANGLE

Fig. 14



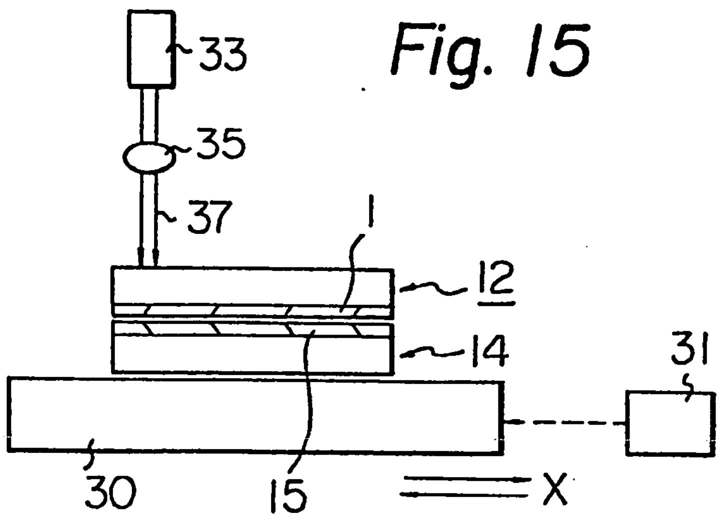


Fig. 15

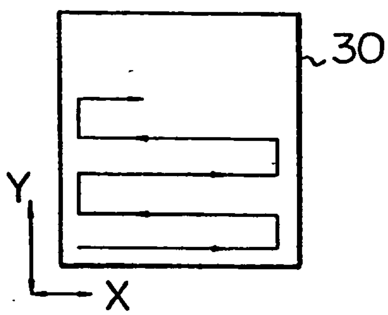
Fig. 16


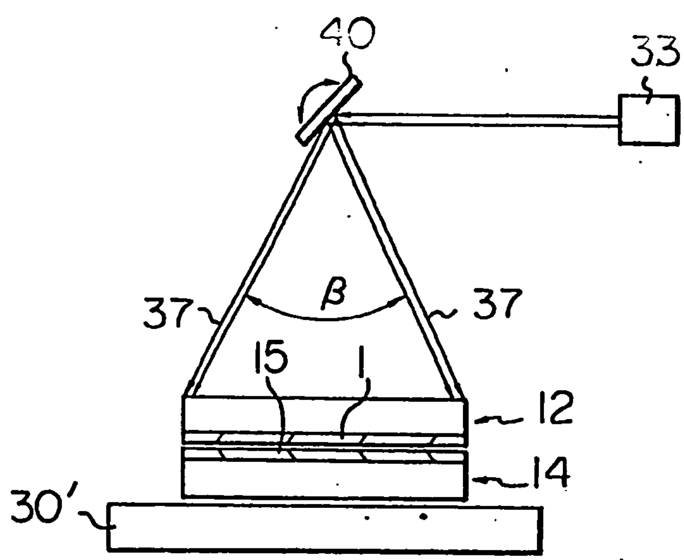
Fig. 17


Fig. 18

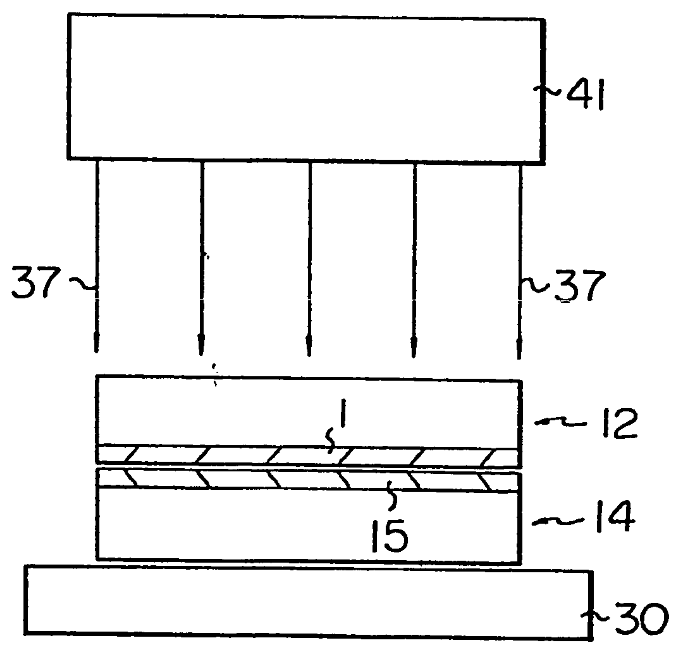


Fig. 19

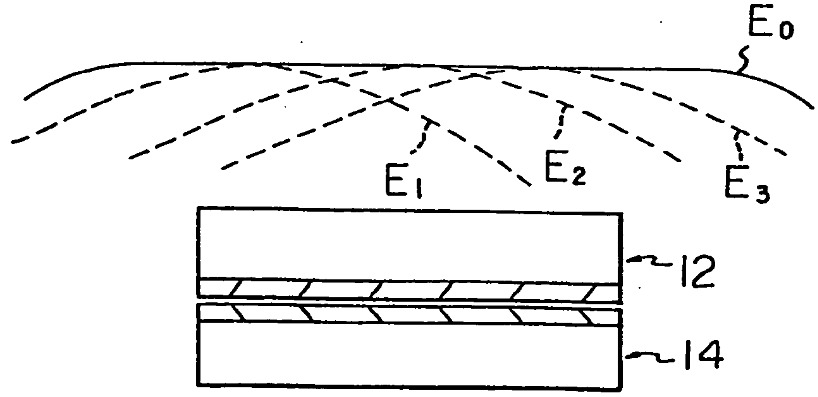


Fig. 20

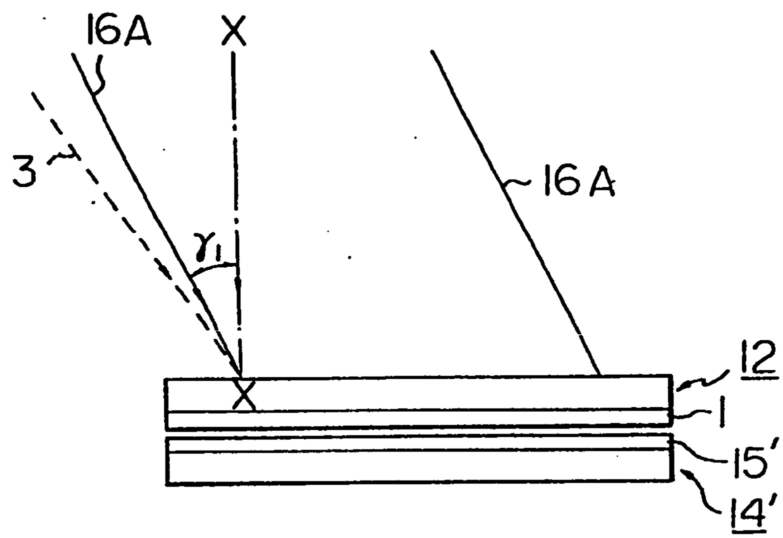


Fig. 21

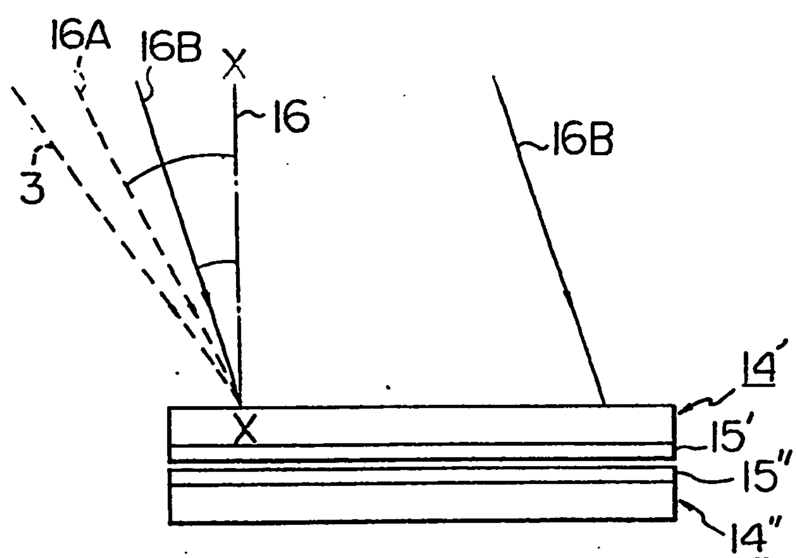


Fig. 22

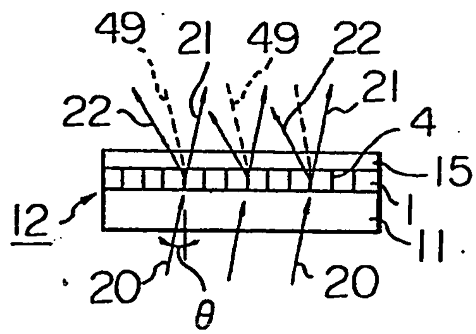


Fig. 23

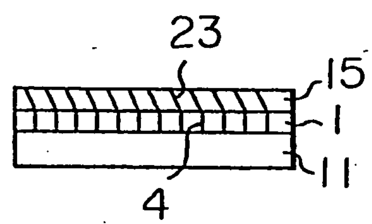
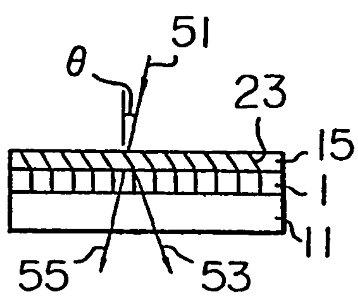


Fig. 24



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EUROPEAN SEARCH REPORT

0087281
Application number

EP 83 30 0833

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl. ³)
			G 03 H 1/20
Y	US-A-3 752 557 (Y. BELVAUX) * Columns 2-3 * ---	1	
Y	IBM TECHNICAL DISCLOSURE BULLETIN, vol. 24, no. 4, September 1981, pages 1896-1897, New York, USA L.D. DICKSON: "Method for producing sub-master holograms" * Whole document * ---	1	
A	IBM TECHNICAL DISCLOSURE BULLETIN ---	3,6	
A	US-A-3 522 979 (R. WUERKER) * Columns 2-3 * ---	12-13	TECHNICAL FIELDS SEARCHED (Int. Cl. ³)
A	US-A-3 647 289 (B.L. WEBER) * Column 4; figure 2 * ---	7	G 03 H 1/20 G 02 B 5/32 G 03 H 1/24 G 06 K 7/10
A,D	US-A-4 235 504 (H. IKEDA et al.) * Columns 9-11 * ---	1	
A	US-A-3 758 186 (D. BRUMM) * columns 4-5; figures 1-3 * ---	5	
A	GB-A-2 049 986 (SONY CORP.) * Page 3; figure 7 * --- -/-	3	

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	29-05-1983	BOEHM CH.E.D.

CATEGORY OF CITED DOCUMENTS

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DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl. 3)
A	SOVIET JOURNAL OF QUANTUM ELECTRONICS, vol. 8, no. 7, July 1978, pages 809-817, Ed. Plenum, New York, USA V.A. VANIN: "Hologram copying (review)" * Pages 809,811,813 * -----	1	
			TECHNICAL FIELDS SEARCHED (Int. Cl. 3)

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	29-05-1983	BOEHM CH.E.D.

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